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Ready, Set, Getting to Go: America's Nuclear Test Readiness Posture

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Abstract

In a geopolitical environment once again dominated by Great Power competition, the stakes of maintaining a credible nuclear deterrent also returned to the forefront of national security. Yet, as nearly thirty years have passed without the United States conducting a nuclear test, there exists considerable uncertainty on how quickly, or even if, the United States could resume nuclear testing—a key component of a credible deterrent. However, there remains a legal requirement, with origins in hard-earned Cold War lessons, for the nation to return to underground nuclear testing if called upon to do so. This paper provides an overview of nuclear testing, the nation's current state of preparedness, and offers recommendations on how to improve its test readiness posture.

Dedication

This research is dedicated to all the nuclear testing experts that informed this research. While it would be easy to take a path of least resistance in retirement, I'm blown away by your continued work ethic, dedication to our nation's national security, and your passion to pass on your hard-won lessons to ensure the next generation is ready to execute nuclear tests if called upon by our nation to do so.

Acknowledgments

I would like to thank all the scientists, current and retired, at Los Alamos National Laboratory for their incredible support and patience in explaining testing 101 to the uninitiated. Also worthy of commendation is the US Air Force for being the only service willing to send nuclear fellows to intern at National Laboratories. And finally, to my friend, mentor, and Los Alamos colleague, Kirk Otterson, whose research and editing skills were paramount in transforming this research into something presentable.

Ready, Set, Getting to Go: America's Nuclear Test Readiness Posture

"We will always remember. We will always be proud. We will always be prepared, so we may always be free."
President Ronald Reagan commemorating the 40th anniversary of the Normandy Invasion, June 6th, 1984

As the geopolitical environment has returned to one of Great Power competition, and nearly thirty years have passed without the United States conducting a nuclear test, there exists considerable uncertainty on how quickly, or even if, the United States could resume testing if deemed necessary by senior leadership. However, there remains a legal requirement for the nation to return to underground nuclear testing if called upon to do so.[1], [2]

This mandate is codified in former President Clinton's Presidential Decision Directive (PDD-15). Signed in 1993, it requires the nation to be able to return to a testing footing within two to three years.[3] The context and importance of the geopolitical forces leading to this directive are hard to overstate. The Cold War had just ended. The Berlin Wall had fallen. Both superpowers were six years into a successful arms control regime, the Intermediate-Range Nuclear Forces (INF) Treaty, and the signatories were well on their way to eliminating an entire class of medium range nuclear missiles.[4] President George H.W. Bush had implemented a nuclear testing moratorium in 1992. Furthermore, in an effort to reassure the Russians that the United States would not take advantage of their tenuous strategic situation following the collapse of the U.S.S.R., Bush directed several unilateral "Presidential Nuclear Initiatives" (PNI's) to

[1] National Security Council and National Security Council Records Management Office, "PDD-15 - U.S. Policy on Stockpile Stewardship Under an Extended Moratorium and a Comprehensive Test Ban, 11/3/1993," *Clinton Digital Library*, https://clinton.presidentiallibraries.us/items/show/12743. Signed by President Clinton on 3 November, 1993, stipulates that the U.S. must maintain a capability to resume testing and "…a capability to conduct a nuclear test within two to three years will be assumed the Department of Energy."

[2] Also, the Senate passed 98-1, S. 1050, the FY2004 National Defense Authorization Bill Sec 3133 that directed the Secretary of Energy to achieve the ability to conduct a nuclear test within 18 months of a decision to test. (Medalia, Comprehensive Nuclear-Test-Ban Treaty: Updated "Safeguards" and Net Assessments 2009) and (H. F. U.S. Congress n.d.)

[3] U.S. Department of Justice, Office of Legal Counsel, Opinions, "Legal Effectiveness of a Presidential Directive as Compared to an Executive Order. According to a Memorandum for the Counsel to the President, 29 January 2000," https://www.justice.gov/file/19436/download. Both an executive order and a presidential directive remain effective upon a change in administration unless otherwise specified in the document and both continue to be effective until subsequent presidential action is taken.

[4] The INF Treaty was signed in 1987 and was a landmark arms control agreement eliminating both the Soviet SS-20 and the U.S. Pershing II mobile medium-range ballistic missiles.

reduce the U.S. nuclear alert posture vis-à-vis the former Soviet Union.[5] Building on the experience and success of INF, a groundbreaking strategic nuclear treaty, the Strategic Arms Reduction Treaty (START), was under negotiation to drastically cut the number of the world's strategic, longer ranger nuclear weapons.[6]

So, by the early 1990s it looked as if "history had ended," to paraphrase Francis Fukuyama's famous declaration made to mark the tectonic shift in the here-to-fore bipolar struggle between competing superpower ideologies. And to put a finer point on it, President George H.W. Bush proclaimed the possibility of a "new world order," in a speech before Congress on September, 11, 1990.[7] Peace, at least in the Cold War strategic sense, had broken out…it seemed.

Within this revolutionary historical context, the United States elected William Jefferson Clinton as its 43rd president and he assumed office in January, 1993. Clinton rode the "end of the Cold War" euphoria into the White House in part based on his promises to reduce militarism throughout the world. However, less than a year into his first term, he signed PDD-15, which stipulated that the United States must be ready to resume nuclear testing "within two to three years" if directed by the President. Perhaps informed (arguably) after Ronald Reagan adopted "Trust, But Verify" as his dictum, the Clinton national security and defense establishment also directed that a number of "safeguards," extant since 1963, be dusted off, reviewed, and updated for inclusion in the PDD.[8] These safeguards represented a set of conditions that U.S. administrations since the 1960s, including Congress and the Joint Chiefs, identified

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[5] Susan J. Koch, *The Presidential Nuclear Initiatives of 1991-1992, A Case Study* (Washington D.C. National Defense University Press, 2012), https://ndupress.ndu.edu/Portals/68/Documents/casestudies/CSWMD_CaseStudy-5.pdf The PNIs were declarations made by President Bush in the 1991-'92 timeframe. While unilateral in nature, they were intended to seize the initiative in arms control and elicit reciprocity from his Soviet/Russian counterparts.

[6] START built upon INF in the sense that similar reductions of weapons, in this case, ICBM'S, SLBM'S and strategic nuclear-capable bombers were planned. Additionally, components like the verification framework and counting rules were refined based on the INF experience.

[7] George, H.W. Bush, "September, 11th, 1990: Address Before a Joint Session of Congress," Presidential Speeches, George H.W. Bush Presidency, The Miller Center, University of Virginia, accessed March 28, 2020. https://millercenter.org/the-presidency/presidential-speeches/september-11-1990-address-joint-session-congress. The speech and phrase "new world order" were given in the context of the 1990 Persian Gulf War. Bush used it again in another speech to Congress on March 6, 1991, at the conclusion of the Gulf War. President Gorbachev expressed similar language in a speech before the UN General Assembly in December, 1988. The phrase quickly became associated with the idea of Great Power cooperation, especially in the reduction of nuclear weapons as opposed to the competition of the Cold War.

[8] As explained in the Charlton Heston's 1989 narrated documentary "Trust, But Verify," Reagan borrow this expression from a Russian proverb. https://www.youtube.com/watch?v=9__uQz5IRI8

as critical to ensuring the readiness of the entire U.S. nuclear enterprise to preclude any strategic/technological surprise.[9]

Certainly, weighing the merits of a resumption of nuclear testing is a complex topic that must consider whether it is necessary, strategically prudent, or fiscally affordable. As such, the decision to actually resume nuclear testing is beyond the scope of this paper. Rather, this paper focuses on a related, and less politically charged subject—whether the United States is actually ***prepared***, as mandated by law, to return to nuclear testing. To be clear, nuclear test readiness is not the same as conducting a nuclear test, in the same way that maintaining a credible nuclear deterrent is not the same as exchanging intercontinental ballistic missiles. With this in mind, this paper provides an overview of nuclear testing, outlines the challenges that United States would face to resume testing, considers the likely scenarios that could prompt testing resumption, and makes recommendations on how to improve nuclear testing readiness.

Ready: What Is Nuclear Testing and Where Do We Stand Today?

To understand the complexity, challenges, and nuance associated with accomplishing, or being prepared to accomplish, nuclear tests, it is helpful to understand some of the basics of testing. One key takeaway is that not all nuclear tests are alike. Rather, there exists a variety of testing options the U.S. has executed over its history. Each of these options has tradeoffs regarding cost and complexity, as well as their own specific purpose. Another highlight pertaining to test readiness is the legal requirements to do so stipulated in PDD-15. Based on several challenging Cold War experiences, the U.S. adopted measures (e.g. the safeguards mentioned earlier) to help ensure it remained postured and ready to return reasonably quickly to testing if geo-strategic conditions and/or technology made this prudent. Lastly, nuclear testing is an extremely complex task that requires coordination across numerous scientific disciplines. Successfully bringing these disparate specialties together is challenging and testing itself is as much an art as it is

[9] Jonathan Medalia, *Comprehensive Nuclear-Test-Ban Treaty: Updated "Safeguards" and Net Assessments* (Congressional Research Service, Washington D.C., 2009) https://crsreports.congress.gov

a science. Unfortunately, the practitioners of the *art of testing* are becoming an endangered species as the nation approaches nearly thirty years without a nuclear test.

A Spectrum of Nuclear Testing

Starting with the Trinity Test on July 16, 1945, the U.S. has conducted a total of 1,054 nuclear tests—more than any other nation.[10] These tests spanned a wide spectrum, varying greatly in scope and purpose. That said, most tests aimed at advancing the collective understanding of nuclear science and weapons design generally fell into one of two categories—Department of Energy/scientific tests or Department of Defense/military tests. The vast majority of these tests were accomplished under the direction of the Department of Energy (DOE) or its predecessor the Atomic Energy Commission. These tests tended to focus on gaining a better understanding of the science behind nuclear weapons. Less frequent, the Department of Defense (DOD) tests primarily focused on understanding whether stockpile weapons met military requirements for performance and safety.

Regardless of the sponsoring department or purpose, underground nuclear tests share three requirements: an emplacement site, that is typically a shaft, tunnel, or cavity, to ensure containment of the radioactive products of the detonation; a nuclear explosive device; and a diagnostic suite capable of capturing data.[11] While all tests share these basic attributes, the complexity and cost of a given test varies greatly with the type of emplacement required, the type of device tested, and the type of scientific data captured.

As shown in Figure 1, tests on the left end of the spectrum tend to be relatively simple and cheap to execute. Tests on the right, which require more sophisticated devices, diagnostics, and emplacement, are generally costlier and more complex. When considering the tradeoffs associated with creating an emplacement site, drilling vertical shafts is typically less expensive than digging tunnels or hollowing out

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[10] National Nuclear Security Administration Nevada Field Office, *United States Nuclear Tests July 1945 through September 1992* (U.S. Department of Energy, Office of Science and Technical Information, Oak Ridge, TN, 2015) https://www.nnss.gov/docs/docs_LibraryPublications/DOE_NV-209_Rev16.pdf. This number is 50% more than the next closest country, the former Soviet Union with 715 tests. See https://www.armscontrol.org/ factsheets/ nuclear testtally for a quick tally of tests.

[11] Dr Michael R. Furlanetto (Deputy Program Director for the Office of Experimental Sciences, Associate Laboratory Directorate for Weapons Physics, Los Alamos National Laboratory), interview by author. Los Alamos, NM, September, 26th, 2019.

cavities within a mountain. Regardless of the type of test, any emplacement site must be designed to effectively contain its nuclear yield. Larger explosions typically require shafts, while tunnels or mined cavities are generally only able to accommodate smaller yields. Regarding the tradeoffs associated with devices, highly optimized and novel devices are more complex and costlier to test than proven designs. Finally, the costs and complexity of developing a proper diagnostic suite can vary greatly. It is difficult to develop equipment that is accurate enough to capture data transmitted over fractions of microseconds yet safe enough to ensure radiation doesn't leak into the atmosphere via the diagnostic tool.[12] A short discussion on each type of test in the testing spectrum follows below.

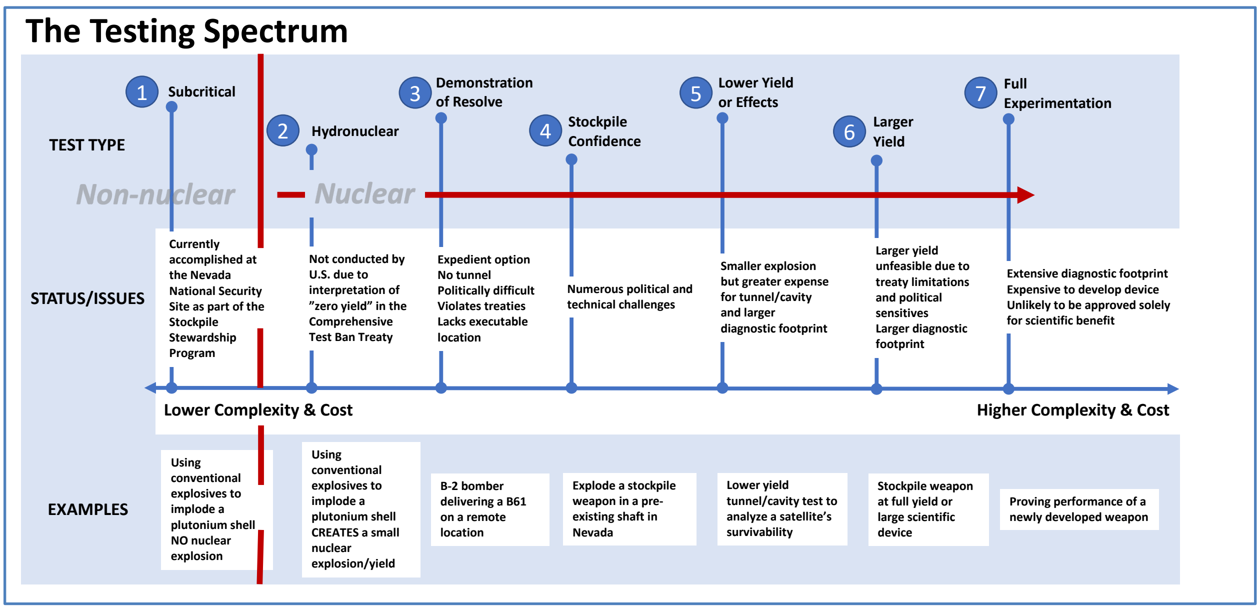

Figure 1. The Testing Spectrum.

Subcritical Tests. These tests (as illustrated on the far left/low cost, low complexity end of the Figure 1) are still performed at the Nevada National Security Site. Since they don't produce any nuclear yield, they don't violate any nuclear testing treaty and don't require containment.[13]

[12] Wendee Brunish, *Containment of Underground Nuclear Tests: A Primer* (Los Alamos: Los Alamos National Laboratory, 2014)

[13] Test devices don't reach critical mass, which is the minimum amount of nuclear material needed to realize a self-sustaining chain reaction -- so while fissions occur because there is a convergent chain, these don't multiply because the system is subcritical and a self-sustaining chain reaction isn't possible. These tests conform with the U.S interpretation of language in the Comprehensive Test Ban Treaty, discussed later in this paper.

These tests are key contributors to the science-based Stockpile Stewardship Program (SSP).[14]

Hydronuclear Tests. Increasing in complexity and cost are hydronuclear tests that generate minimal nuclear yields, typically less than the chemical energy released by the explosives used in the test.[15] These are not conducted by the U.S. given how it interprets the Comprehensive Test Ban Treaty (CTBT) Article I language to preclude *any* nuclear explosion—no matter how small, in other words, *zero yield*.[16] However, hydronuclear tests would facilitate an improved understanding of the behavior of plutonium relative to subcritical tests.

Demonstration of Resolve Tests. These show of force tests would most likely be used in response to a geopolitical event where speed of response is at a premium to deter an adversary from conducting further nuclear explosives testing, or more provocative measures. For example, a B-2 bomber could deliver a B61 thermonuclear weapon on open ocean to demonstrate the U.S. deterrent/assurance credibility to allies and adversaries. This kind of test would be relatively simple and comparatively cheap to conduct as it requires no emplacement site/underground footprint, little to no diagnostics, and would likely use a stockpile weapon. Of course, the political barriers to actually conducting a test like this would be extremely high and may require the abrogation of the Limited Test Ban Treaty (LTBT) "precludes parties to the treaty from conducting any tests outside their territory that would cause radioactive debris to enter the atmosphere."[17] Additionally, the lack of a suitable location to conduct an above ground nuclear explosion would be extremely challenging.

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[14] Joseph Martz, "Detonation from the Bottom Up," *National Security Science Magazine*, (July 2014): 3-14. https://www.lanl.gov/discover/publications/national-security-science/2014-july/_assets/docs/NSS_JUL2014_Bottom.pdf.

[15] Dr Michael R. Furlanetto (Deputy Program Director for the Office of Experimental Sciences, Associate Laboratory Directorate for Weapons Physics, Los Alamos National Laboratory), interview by author. Los Alamos, NM, September, 26th, 2019.

[16] U.S. Congress, Senate, Committee on Foreign Relations of the United States, *Final Review of the Comprehensive Test Ban Treaty: Hearings before the Senate Foreign Relations Committee*, Statement by Ambassador Stephen J. Ledogar (Ret.), 106th Cong., 1st sess., October 7th, 1999. In testimony, the chief U.S. negotiator, Amb. Ledogar stated unequivocally that zero yield meant exactly zero yield and that at the time, the negotiating parties to the treaty, including Russia, understood that language. https://www.govinfo.gov/content/pkg/CHRG-106shrg61364/html/CHRG-106shrg61364.htm

[17] U.S. Department of State, *Treaty Banning Nuclear Weapons Tests in the Atmosphere, in Outer Space, and Underwater*, October 10th, 1963. https://2009-2017.state.gov/t/avc/trty/199116.htm

Given these likely insurmountable issues, an underground test to demonstrate resolve *promptly* would be more likely. However, challenges to an underground test are hardly trivial. The major issue is location. While the Nevada National Security Site (NNSS) offers an optimum location in terms of a pre-existing holes and geographic suitability, the NNSS is no longer the relatively remote location it once was in the 1950s and 1960s. Las Vegas has grown considerably and the risks of testing in proximity to a large urban area, as well as large military installations such as Nellis and Creech Air Force Bases, would require considerable deliberation. Other potential underground test sites also pose significant challenges. This is discussed later in the paper.

Stockpile Confidence Tests. These tests, designed to prove the performance of an aging stockpile weapon, would be similar to an underground *demonstration of resolve* test described above. A pre-existing hole would be needed as would a stockpile weapon. However, to capture the required performance data (not a necessity when simply demonstrating resolve), a sophisticated diagnostic suite would be essential. These tests would also pose the same locational challenge described in the previous paragraph.[18]

Lower Yield or Effects Tests. These tests would likely be conducted in a pre-existing shaft or tunnel at the NNSS and require a larger diagnostic footprint than the stockpile confidence tests. Counterintuitively, lower yield tests may pose a higher risk of an unplanned release of radioactive gasses and thus a danger to nearby populations as they can be harder to contain than larger yield tests.[19] Effects tests tend to be lower yield and are usually exploded in a cavity or tunnel near an object of interest such as a satellite, aircraft, or another nuclear warhead. The scientific purpose is usually to determine how a nuclear explosion affects an object's (e.g., a satellite, an aircraft, etc.) survivability in a nuclear

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[18] Kent Johnson et al., *Stockpile Surveillance: Past and Future* (Sandia National Laboratories, NM, 1996) p.4 Beginning in 1970, DOD and DOE agreed to a formal series of underground tests of weapons withdrawn from the Stockpile, these were called Stockpile Confidence Tests. They differed from development nuclear tests in that the weapon was from actual production, had experienced stockpile conditions, and had minimal changes made to either the nuclear or non-nuclear components prior to the tests. https://www.osti.gov/servlets/purl/197796

[19] Wendee Brunish (Retired Los Alamos Containment Group Leader and current Chair of the Containment Evaluation Review), interview by author, Los Alamos, NM, October, 29th, 2019. The BANEBERRY test accident was an example of such a containment failure that occurred in part due to its smaller yield, but also due to the test's proximity to fault lines and other geological features. See *United States Nuclear Tests July 1945 through September 1992.*

environment. Effects tests necessitate more sophisticated diagnostics and more expensive tunnels or cavities. Historically, these were usually conducted by DOD utilizing a DOE supplied device.

Larger Yield Tests. For numerous reasons, these tests would have significant political constraints. Policymakers must not only consider whether to violate or abrogate treaty obligations to achieve a higher yield, but must also choose a test site that will have less risk of creating negative impacts to, for example, the environment.

As discussed later in the paper, in all likelihood, neither the residents of Nevada, their elected officials, nor any other state would be amenable to hosting large nuclear yield tests in their territory.

Full Experimentation Tests. Finally, on the far-right spectrum of testing, full experimentation tests could be the most expensive and complex of all testing options. These would be used to test a new device, necessitate a sophisticated diagnostic suite, and may require drilling a specialized hole to accommodate the test.

The key takeaway from the Testing Spectrum, Figure 1 is that *any* decision to return to testing isn't simply a binary one – i.e., decide to test and conduct a test. Analogous to turning on the lights in a room; U.S. leadership should not expect to *flip a switch* and restore the nation's nuclear test capabilities. A more apt analogy would be to consider the light switch as a "dimmer switch"; in other words, leadership must recognize that varying degrees of testing are available, consider what type of test is appropriate for the situation, **and** understand that the decisions to move from left to right along the spectrum of testing (like turning up a dimmer switch) require a commensurate increase in preparedness, risk, cost, complexity, and national resolve.[20]

In fact, leadership may find that given the current challenges within the nuclear enterprise, supporting and conducting any of the more complex and costly tests further to the right of the relatively simpler tests such as the subcritical ones, could prove extremely difficult within the legally defined timelines specified in PDD-15, i.e., two to three years. And as with any major program involving

[20] Dimmer switch analogy attributed to Dave Steedman, Staff Engineer, Los Alamos National Laboratory. Interview by author, Los Alamos, NM, December, 5th, 2019.

significant organizational, technical, and political challenges the costs are likely to be much higher than initial estimates.[21]

Legal Framework to Resume Testing: PDD-15 and the Safeguards

Even though the U.S. hasn't conducted a full-scale nuclear test since 1992, it retains a legal requirement to be ready to do so as spelled out in PDD-15. Crafted in the wake of decisions over the course of several U.S. administrations to reduce and eventually stop any kind of nuclear testing, the PDD and associated safeguards frame the conditions under which future U.S. leadership would consider a resumption of testing.[22]

The origins of the current test ban began in 1991 when Soviet leader Mikhail Gorbachev unilaterally declared a moratorium on the U.S.S.R.'s nuclear testing. In 1992, President George H.W. Bush followed suit declaring a U.S. testing moratorium. This was formalized in 1996 when President Clinton signed the Comprehensive Test Ban Treaty (CTBT). Although the Senate failed to ratify the treaty, technically leaving the door open for the U.S. to conduct future tests, the U.S. has continued to abide by the spirit of the CTBT and refrain from testing.

PDD-15 also addresses the "safeguards" that were codified alongside nuclear treaties in an attempt to avoid strategic and/or technological surprise by an adversary. The genesis for the safeguards was a resumption of testing by the Soviets in 1961 that surprised the U.S.[23] Following the Soviet test, the Joint Chiefs conditioned their support for future nuclear treaties on an ability to resume testing should geopolitical and/or technological conditions warrant it.[24]

[21] See Appendix A in this paper for a representative sample of historical tests that highlight some of the issues described in this section.

[22] It is important to point out a President can issue a new Executive Order or Presidential Decision Directive with different stipulations that would supersede PDD-15.

[23] Thomas Kunkle, *A Short History of the United States Nuclear Treaty Safeguard Program* (Los Alamos, NM: Los Alamos National Laboratory, 2004)

[24] Medalia, p. 3, Appendix A, According to Medalia, "during the 1963 debate on the ratification of the Limited Test Ban Treaty (LTBT), the Joint Chiefs of Staff expressed concern that the treaty would lead to euphoria and cause the U.S. to let down its guard against the Soviet Union."

These safeguards have evolved over time, modified as various treaties were negotiated. Generally, they stipulate that U.S. maintain readiness in the following areas:[25]

- Safeguard A: to conduct of underground testing or stockpile stewardship
- Safeguard B: to maintain laboratories and human scientific resources
- Safeguard C: to maintain the capability to resume nuclear tests prohibited by treaties
- Safeguard D: to conduct research and development to improve treaty monitoring
- Safeguard E: to develop intelligence programs to monitor nuclear programs of other nations

While all these safeguards are important elements of nuclear deterrence, Safeguard A relates explicitly to underground testing readiness. And while attempts were made in 1997 and 1999 to adjust this safeguard by removing verbiage requiring a return to an "underground nuclear test program" and replace it with scientific assurances based on the Stockpile Stewardship Program, the most recent set of safeguards, which were ratified by the Senate, and remain legally binding, were contained within the Threshold Test Ban Treaty (TTBT) and the Peaceful Nuclear Explosions Treaty (PNET) both entering into force on December 8, 1990.[26]

In summary, the PDD and associated safeguards were put in place to ensure that regardless of the direction of the geopolitical winds of the period, the U.S. would remain ready to resume testing. As stated earlier, nuclear testing is as much art as it is science. The next section will examine this art and science in greater detail.

The Art and Science of Nuclear Testing

A successful and safe nuclear test involves considerably more than a well-designed nuclear device. These tests are comprehensive and complex tasks that span myriad scientific disciplines and require keen organizational acumen to bring disparate specialties together before, during, and after the event to establish the test parameters, set up the testing location, prepare, analyze the resultant data, and

[25] Medalia, Appendix A, p. 21

[26] Kunkle.

conduct follow-on analysis and review lessons learned. Only when this occurs, does a test render the incredible scientific feat of nuclear fusion and fission safely, punctually and on budget.

A highly skilled *team* is absolutely essential to the conduct of a successful underground nuclear test. The hyper-intelligent engineers and scientists must work in concert to develop a device that transforms itself into heat, light, and radiation. Equally important are the talented and sometimes overlooked groups of geologically focused physicists, engineers, and organizational experts who collaborate to develop a plan not only to emplace these devices hundreds to thousands of feet underground, but also to prevent nuclear debris from reaching the surface and entering the atmosphere. Given the complexities and difficulties of controlling for numerous geological unknowns, the containment of a nuclear explosion is really an equal combination of art and science and relies heavily on the experience gained from hundreds of previous nuclear tests.

Once all the necessary coordination and planning has occurred, the team moves to the test site. All the science and art literally come together at the testing location. Broken down into basic steps, the following actions occur. A hole is drilled, possibly thousands of feet deep, in a geologically suitable location that mitigates the risk of nuclear material escaping to the surface via a pre-existing fault or fracture or an explosively driven hydrofracture. A diagnostic rack or canister that contains the nuclear device, surrounded by sophisticated and precisely-placed instruments, is emplaced in the hole. Cables are run from the rack in the hole to data collection centers. The hole is filled with alternating layers of fines (sand) and coarse (gravel) and impermeable plugs (typically grout or epoxy) to prevent the radioactive gasses generated by the nuclear explosion from escaping back up the hole and into the atmosphere. While these steps sound straightforward, each one has a myriad of highly technical sub-steps and actions that require an exacting level of detail to ensure the safe and successful execution of the nuclear test.

Above and beyond this army of highly trained underground nuclear test specialists are requirements for complex equipment such as high output neutron generators, specialized diagnostic materials, radiochemical detectors, drills capable of auguring large and deep holes, special cranes to lower the diagnostic rack, gas-blocked cables, and sophisticated test equipment capable of safely and accurately transmitting data in the microseconds ahead of an explosion moving at the speed of light. The assembly and delivery of the nuclear device itself is also time consuming and requires coordination among multiple organizations and associated facilities. It is the orchestration of this "ballet" or "symphony" of activities that makes conducting an underground nuclear test truly an art form.

The Current State of Nuclear Test Readiness

Before examining the obstacles associated with a potential resumption of underground nuclear testing, it is important to review the positive attributes of the current testing posture with regard to the safety, security, and effectiveness of the nuclear stockpile. This status is best understood through the lens of the Stockpile Stewardship Program (SSP).

The SSP was authorized by Congress in response to the 1992 nuclear testing moratorium, "to ensure the preservation of the core intellectual and technical competencies of the U.S. in nuclear weapons."[27] Absent a program of underground testing, the nuclear enterprise had to leverage science in a novel way to gain a deeper understanding of "…weapons design, system integration, manufacturing, security, use control, reliability assessment, and *ultimately* certification *of the device*."[28] Embracing its mandate forcefully, the SSP pioneered numerous scientific inventions and tools, some of which are one-of-a-kind, to ensure the safety, security, effectiveness, and reliability of stockpile via "…a combination of weapons surveillance (i.e., disassembly and identification of mechanical problems), nonnuclear tests, and computer modeling."[29]

The Surveillance Program. A major concern of the SSP is to address the advanced age of stockpile weapons. Given that the current stockpile weapons are considerably older than their initially designed shelf life, a cornerstone of SSP is the surveillance program that monitors a weapon's health. This program employs some of the world's best scientists to better understand the effects of aging on all components within a weapons system--nuclear and non-nuclear. A main focus of surveillance is to understand how plutonium, one critical fissile material used to drive a nuclear reaction, would age and

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[27] U.S. Congress, House, *Fiscal Year 1994 Defense Authorization Act*, Section 3138. 103rd Cong., 1st sess., January, 5th, 1993. https://www.congress.gov/bill/103rd-congress/house-bill/2401/text

[28] Medalia, p.5, Note, the words in italics are the author's for clarity and not included in Medalia's CRS report.

[29] Los Alamos J-Division (Weapons Experiments) Publication, "Dual Axis Hydrodynamic Radiographic Test (DARHT): Validating Weapons Performance without Nuclear Testing," (November 2018): p. 2

how this aging could affect a weapon's performance. Periodically, stockpile weapons are returned to the national laboratories to perform "weapons autopsies" to look for aging and other defects.[30]

Nonnuclear Testing. Another fundamental component of SSP is the requirement to conduct nonnuclear testing. These tests are primarily performed at the NNSS and national laboratories within the nuclear enterprise (i.e., the National Nuclear Security Administration) using some of the nation's most unique facilities and novel instruments. Test readiness events are a critical component within the nonnuclear testing arena. Scientists, on a fairly regular basis, engage in these events in Nevada to sharpen their skills.[31] These test readiness events are often guided by retired scientists, many of whom are the last of their discipline with firsthand nuclear testing experience. These events offer younger scientists a unique and fleeting opportunity to learn from true experts who've "been there and done that."

Recognizing that these experienced scientists won't be around forever, Los Alamos National Laboratory has created the National Security Research Center (NSRC) with the mission is to archive, digitize, catalogue, and make available seventy-five years of classified research materials such as films, drawings, scientists' notes, and other documents to aid future generation's understanding of how to execute a nuclear test as well as a host of other information related to weapon's design, etc.[32]

Subcritical Tests. "Subcrits" are another essential feature of the SSP. Conducted at the NNSS underground facility U1a, these tests use high explosives to dynamically compress plutonium and model its behavior. To be clear, per Executive Order and in accordance with Congressional direction, these tests never produce a critical mass.[33] In addition to the improved understanding gleaned from these experiments, these tests, like the nuclear test readiness exercises, serve as "…the primary method of

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[30] J. Martz, "Detonation from the Bottom Up." *National Security Science Magazine.* (July, 2014) p. 3-14

[31] C. Bradley (Senior Scientist and Los Alamos member to the Containment Evaluation and Review Panel) and G. Euler (Los Alamos Containment Scientist) interview by author, Los Alamos, NM, December, 5th, 2019. Scientists, on a fairly regular basis, engage in testing preparedness events in Nevada such as UNICORN (2005), SPE Phase I in Granite (2011-2016), and SPE Phase II in Alluvium (2018-2019) to sharpen their skills.

[32] The NSRC houses the largest collection of national security and nuclear weapons documents in America, with an expert staff of research librarians and archivist. The Center's collections encompass work produced not only at Los Alamos, but across the nuclear enterprise in the DOE and DOD. Ali, Rizwan, Director, Los Alamos National Security Research Center, interview by author. Los Alamos, NM, April, 6th 2020.

[33] J. Martz, "Detonation from the Bottom Up," p.11

training the next generation of diagnosticians while at the same time exercising many of the fielding capabilities that would be used for an underground nuclear test."[34]

Dual Axis Radiographic Hydrodynamic Test (DARHT). Complementing the subcritical experiments is Los Alamos National Laboratory's DARHT facility. DARHT is a high-tech invention that provides a "rich suite of diagnostic measurements" that allows scientists to model the microseconds during a "weapon's crucial triggering phase" when the conventional explosives that surround the nuclear fuel are detonated. Aside from being one of the world's most powerful x-ray machines, the advanced data DARHT provides is second only to an actual nuclear test in understanding an implosion's progress.[35]

National Ignition Facility (NIF). Another important contributor to nonnuclear testing is Lawrence Livermore National Laboratory's NIF. The NIF has the distinction of being the world's "largest and most energetic laser facility every built." Goals of the NIF mission are to pursue fusion ignition, improve scientific understanding across numerous disciplines, and help ensure the reliability of the nation's nuclear stockpile – without testing which is of course fundamental to the SSP.[36]

Los Alamos Neutron Science Center (LANSCE). The LANSCE facility provides a linear accelerator producing neutron and proton beams and detector arrays for industrial and defense research.[37] A portion of those beams function in a uniquely developed science known as proton radiography (pRad), which "uses protons to take images of many of the materials in the physics package at pertinent times with high contrast. Proton radiography is especially well suited to studies of the movement of waves inside the explosives themselves." Proton radiography offers an enhanced capability (e.g., beyond x-ray radiography) to understand the underlying physics of what drives a nuclear explosion.[38]

Electromagnetic Environments Simulator (EMES) and the Z-Machine. Sandia National Laboratory is home to two unique machines that are able to test objects in extreme environments. The

[34] Nevada Operations Office, p.15

[35] Los Alamos J-Division Publication on DARHT

[36] "What is NIF?," Lawrence Livermore National Laboratory, https://lasers.llnl.gov/about/what-is-nif (accessed January 22nd, 2020)

[37] "Los Alamos Neutron Science Center, Weapons Neutron Research Facility," Los Alamos National Laboratory, https://lansce.lanl.gov/facilities/wnr/index.php (accessed April 21st, 2020)

[38] J. Martz, "Detonation from the Bottom Up," p.12

EMES is used to conduct susceptibility testing by sending electromagnetic waves through objects of interest and, to some degree, explores some of the same vulnerabilities as nuclear effects tests.[39] Likewise, the Z-Machine "provides the fastest, most accurate, and cheapest method to determine how materials will react under high pressures and temperatures."[40]

Supercomputing. Scientists use data from data from past nuclear tests, coupled with data supplied by SSP's surveillance and nonnuclear test programs, to simulate and hopefully verify results from extremely sophisticated computer codes used to model the behavior of nuclear weapons. These simulations run on some of the world's largest and fastest computers.[41] Programs such as Los Alamos' Advanced Simulation and Computing (ASC) Program develop simulation capabilities and deploy computing platforms to "analyze and predict the performance, safety, and reliability of nuclear weapons and to certify their functionality in the absence of nuclear testing." The codes developed by the scientists and computed by these computers serve as a key component to certifying effectiveness of the nation's nuclear stockpile.

The facilities, programs, and technology described above represent only a fraction of the numerous scientific tools used throughout the nuclear enterprise to support the SSP. The ability to model the extraordinary complexity of nuclear weapons systems is absolutely essential to the SSP, which is, after all, reliant on science and numerical simulation absent actual nuclear testing.

Interestingly as explained by senior Los Alamos scientist Joseph Martz, it is somewhat ironic that the inability to test weapons and produce a nuclear yield has, in certain aspects, actually led to a *better* scientific understanding of how the weapons work. In the past, having a testing capability meant scientists didn't need to understand all the details of a nuclear weapon to assess weapon performance. He went on to explain that while nuclear testing was a "unique and wonderful tool, it was also the world's

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[39] "Electromagnetic Environments Simulator," Sandia National Laboratory, https://www.sandia.gov/research/research_foundations/electromagnetics/facilities/large_transverse_em_cell.html (accessed April 8th, 2020)

[40] "Z Pulsed Power Facility," Sandia National Laboratory, https://www.sandia.gov/z-machine/ (accessed April 8th, 2020)

[41] Fred Mortensen. (Los Alamos Fellow and Design Leader) interview by author. Los Alamos, NM, April, 25th, 2020.

biggest shortcut. SSP has forced today's scientists to do their homework and model a device's physics and engineering at a much greater level of detail than in the past."[42] Since 1996, every director of each of the national nuclear security laboratories has signed twenty-four annual assessment letters to the Secretaries of Energy, Defense, and the Chair of the Nuclear Weapons Council. Every letter to date has reported that there was no need to conduct nuclear testing to maintain the certification of the warheads/bombs for which each laboratory is responsible.[43]

Difficulties in Resuming Testing

While the SSP has worked for twenty-four years to improve the safety and security, and to certify the effectiveness of the nation's stockpile, significant challenges exist in a number of areas should a U.S. administration decide to resume nuclear testing.[44] These challenges include personnel and infrastructure atrophy, a complicated but necessary regulatory environment, and the lack of a viable location to conduct a nuclear test.

Personnel. Given that the last underground nuclear test was performed over twenty-five years ago, the U.S. lacks personnel, specifically geophysicists, physicists, and engineers, with hands-on experience not only performing these tests but also some of the essential associated experimentation. At its peak, Los Alamos had approximately 4,000 people contributing to the test program, while the test site in Nevada employed 7,000 individuals.[45] With the reduced scope of nonnuclear tests, the number of people involved devoted to testing is a fraction of what it once was. According to Wendee Brunish, retired Los Alamos Containment Group Leader and current Chair of the Containment Evaluation Review,

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[42] J. Martz, Senior Staff Scientist, Los Alamos National Laboratory, interview by author, Los Alamos, NM, October, 15th, 2019.

[43] Sieg Shalles (Director, Office of Stockpile Assessment), interview by author, Los Alamos, NM, February, 26th, 2020.

[44] *Nuclear testing* refers to any test that would generate a nuclear yield however small.

[45] John C. Hopkins, (Former Los Alamos Laboratory Associate Director, responsible for Nuclear Weapons Program) interview by author. Los Alamos, NM, October, 8th 2019

the most crucial loss impacting test preparedness is "…the expertise that allowed us to produce and evaluate containment designs has greatly diminished and will soon be almost non-existent."[46]

Equipment and Infrastructure. While thirty-three predrilled holes exist, that could be used for an immediate test assuming they are still open and stable, the equipment required to safely conduct underground testing has atrophied severely.[47] The ability to emplace a rack or canister has been compromised as the large crane capable of handling this load was salvaged and the wire ropes and pipes required to lower the test device need pull testing to ensure viability.[48] While the remaining unused racks and canisters are helpful for instructional purposes, they may be of limited utility to conduct an immediate test as racks are developed specifically for each test and aren't interchangeable. The specially designed gas-blocked cables that prevent radioactive material from releasing into the atmosphere have been baking in Nevada desert for almost thirty years and there no longer exists a manufacturer to supply replacements.[49]

Furthermore, the ability to manufacture the specialized expansive grout and epoxies used to form the plugs for the shaft that blocks rising debris would need to be reconstituted along with some of the diagnostic instruments used for ground motion analysis.[50] A major question would be whether to invest in new technology to aid in testing or whether it is more prudent to reconstitute proven, but antiquated testing methods. In either case, a two to three-year timeline to test would be a significant challenge given these issues.

Regulatory Environment. Known in DOE parlance as "authorization basis", the regulations that ensure worker, public, and environmental safety have expanded considerably since the early 1990s when the most recent nuclear test occurred. Would the responsible parties be able to navigate this complicated

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[46] Brunish, *Containment of Underground Nuclear Tests: A Primer,* Los Alamos National Laboratory, April 23rd, 2014

[47] Nevada Operations Office, p. 7, 16

[48] John C. Hopkins, "Nuclear Test Readiness: What is Needed? Why?," *National Security Science Magazine*, (December, 2016) p.9

[49] All retired testing experts interviewed for this research highlighted the importance of gas-blocked cables and expressed concerns about the viability of the aged inventory and the ability of the nation to remanufacture replacements.

[50] Nevada Operations Office, p.9

but necessary regulatory environment within the time constraints, two to three years, posed by PDD-15 to resume testing?[51]

A Suitable Location. This is certainly the most significant challenge in any decision calculus regarding a resumption of underground nuclear testing. On the surface, a return to the Nevada National Security Site (NNSS), with its dry soil, porous rock, and deep water table, seems the obvious choice as the deserts of southern Nevada are perhaps the world's best environment for conducting underground nuclear tests.[52] However, Nevada now has considerable disadvantages that didn't exist during the nuclear testing heyday. Specifically, the region's population boom makes the effects of testing potentially much more damaging and potentially hazardous than before. The greater Las Vegas metropolitan area, which had a population of 25,000 in 1951, blossomed to 700,000 inhabitants by 1992 when it hosted its most recent nuclear test. Since then, this growth has intensified as the area has transformed into one of the world's premier tourist destinations with a population of 2.1 million.[53]

In the past, tourists flocked to Las Vegas' hotels and casinos to witness and feel atomic explosions. Back then, DOE put seismometers on high rise buildings, checked building plans, and maintained extensive files on buildings throughout the valley to monitor structural resiliency.[54] However since the apex of Las Vegas "nuclear tourism" in the 1950s and 1960s, casinos have grown significantly taller and the distance between the highly populated Las Vegas metropolitan area and the NNSS has shrunk considerably.[55] Given these factors, any further nuclear testing operations in southern Nevada, other than perhaps small (hydronuclear) or no-yield tests that reside on the left side of the spectrum in Figure 1, are probably highly unlikely.

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[51] Nevada Operations Office, p.37, appendix E

[52] C. Bradley, (Senior Scientist and Los Alamos member to the Containment Evaluation and Review Panel) interview by author, Los Alamos, NM, December, 5th, 2019

[53] John C. Hopkins, "Nuclear Test Readiness: What is Needed? Why?," *National Security Science Magazine*, (December, 2016) p. 10

[54] Hopkins, interview by author, October, 8th 2019

[55] Glen McDuff, (Los Alamos Research Scientist, retired) and Keith Thomas (Los Alamos Research Scientist), Interview by author, October, 1 2019 and Primer: "Underground Nuclear Testing" LA-UR-18-24015 (McDuff, Primer: "Underground Nuclear Testing" LA-UR-18-24015 2019)

For many of the same reasons, other alternative locations would also likely be off limits. Historical test locations such as New Mexico, Alaska, Mississippi, and Colorado pose many of the same challenges to host testing as Nevada. Some experts view Amchitka Island in Alaska's Aleutian Island chain as a possible site given its past testing history and remote location. However, as the decades have passed since the last tests conducted there in the 1960s and 1970s, its infrastructure has decayed. The significant distance from the mainland would likely make test operations expensive not to mention inconvenient. [56] The political challenges are probably even more formidable than the logistical ones. Amchitka Island is part of the Alaska National Maritime Wildlife Refuge and the island still bears the scars from its 1971 nuclear test.[57] Given the known difficulties of performing activities like offshore drilling in nationally designated wildlife refuges, its highly likely that any suggestion to conduct a nuclear test there would be politically dead on arrival.

Organizational Challenges. While the issues described so far are significant in their own right, the organizational problems posed in planning and conducting a nuclear test are equally daunting. In nuclear testing, the sum of the parts required to execute a test is not equal to the whole of actually executing a test. According to NNSA, functional test readiness is broken into at least fourteen specialized areas: containment, security, assembly, storage and transportation, insertion, emplacement and stemming, timing and control, arming and firing, diagnostics, test control center activities, post-shot drilling, nuclear design, weapons engineering, test integration, and nuclear chemistry.[58] All these specialized areas, either complement or are in addition to, the aforementioned challenges in that they represent a unique level of complexity. In the words of one experienced Los Alamos nuclear tester, "a successful test requires developing the nuclear design, organizing the porta-potties for the test site, and everything in between!"[59]

While each of these entities can and does maintain its own capabilities through a variety of day-to-day work, exercises, etc., it's important to appreciate the organizational challenges that must be

[56] Hopkins, interview by author, October 2019.

[57] The 1971 Cannikin Test was one of the largest underground nuclear tests, according to Greenpeace's website, was the impetus for its formation.

[58] Nevada Operations Office, Appendix F

[59] Glen McDuff, (Los Alamos Research Scientist, retired) interview by author, October, 1st, 2019

overcome to integrate these fourteen specialties as part of an entire system in order to conduct an underground nuclear test. As explained by a Sandia National Laboratory scientist:

> "By exercising all of the skills and capabilities required to design, test, qualify, and produce complete systems on a regular basis, those skills are ready and available to address higher-priority problems on a moment's notice. The complex must exercise all of the skills required, not just the science, modeling, and simulation skills, to have them available. These skills include but are not limited to a strong scientific foundation, systems analysis, engineering analysis, design definition, systems engineering, component design, test and evaluation, component production, and weapon assembly and disassembly. Like an athlete, you cannot exercise 20 percent of the skill base and expect to function at 100 percent on game day. You have to practice all parts of you craft or you will not be able to perform up to expectation when a problem arises unexpectedly."[60]

As the saying goes, "Close only counts in horseshoes and hand grenades;" should the U.S. decide at some point to resume or conduct an underground nuclear test, *close* isn't good enough. The test must be executed flawlessly without mistakes.[61]

Equipment atrophy, a lack of experienced personnel, and location and organizational challenges put the U.S. in a tenuous position should leadership decide it is necessary to conduct an underground nuclear test in accordance with the timeframe specified by PDD-15. As illustrated in Figure 1, even relatively simpler tests towards the left end of the testing spectrum could prove extremely difficult to pull off within the currently identified time horizon. Two former nuclear test experts opined it could take five to ten years to return to testing and even then, the risks of containment failures and radioactive release could be significant unless considerable nuclear testing equipment, materials and expertise can be

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[60] Joseph Medalia, *Nuclear Warheads: The Reliable Replacement Warhead Program and the Life Extension Program* (Washington D.C.: Congressional Research Service, 2007)

[61] For an analogous military example of trying to pull a variety of organizations with attendant capabilities together absent *any* or at least recent experience "training together," see "Operation EAGLE CLAW, the failed Iranian hostage rescue attempt. A detailed account of the challenges can be found in Col James Kyle's book *The Guts to Try: The Untold Story of the Iran Hostage Rescue Mission,* (New York: Ballentine Books, 1990)

reconstituted.[62] [63] As the world enters the more challenging age of Great Power competition and its associated risks for conflict, accepting a ten-year timeline to resume testing may itself represent an unacceptable risk to national security.

Set: Arguments "For" and "Against" a Resumption of Underground Testing

The need to resume nuclear testing is a hotly debated subject with many experts holding opinions on both sides of the issue. While this paper does not enter the fray on whether it is in the best interest of national security to actually resume full-scale nuclear testing, when evaluating the nation's test readiness posture, it is useful to understand the context and merits of each position. Ultimately, the nation's senior leadership will continue to weigh whether testing resumption improves or degrades national security. But having a reasonable grasp on the issue of resumed testing is useful in informing the amount of risk the nation is willing to take when considering its test readiness posture. What follows is a brief summary of the pros and cons.

Maintaining the Status Quo: No Resumption of Underground Nuclear Testing

Science and the Stockpile. The efforts of the Stockpile Stewardship Program, which has leveraged science to gain a more in-depth understanding of nuclear weapons since 1992, is probably the most compelling reason to avoid testing – testing simply isn't necessary to certify the safety, security, and effectiveness of the nation's nuclear weapons. The fact that current warheads have extensive nuclear test pedigrees, that the SSP has greatly improved the understanding of weapons science, and that Life Extension Programs (LEP) can extend the life of current warheads by twenty to thirty years, reinforces the health of the stockpile and nullifies any near-term need to resume testing.[64] Thus far, SSP has fulfilled its responsibilities without identifying a scientific question requiring a nuclear test. Additionally, scientific tools which have closed specific knowledge gaps left over from the testing years, have allowed

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[62] Brunish, *Containment of Underground Nuclear Tests: A Primer.* The nuclear enterprise has thus far not formally attempted to derive a more accurate estimate.

[63] Fred Mortensen. (Los Alamos Fellow and Design Leader) interview by author. Los Alamos, NM, April, 25th, 2020.

[64] Medalia, *Nuclear Warheads: The Reliable Replacement Warhead Program and the Life Extension Program*

scientists to test specific parts of nuclear weapons, obviating the need for comprehensive underground nuclear testing.[65]

Non-proliferation, U.S. Leadership, and the Status Quo. U.S. "leadership by example" has been a key factor in limiting the proliferation of nuclear weapons since their inception. While many countries could have pursued the acquisition of nuclear weapons, they refrained or abandoned programs under the "umbrella" of a U.S. led deterrence and assurance policy. Should the U.S. make a decision to resume nuclear testing, this could induce other nuclear states to follow suit in a *testing race* to improve their own stockpiles. Furthermore, under the current status quo where most actors refrain from testing, there exists a relatively stable equilibrium in which ignorance (or ambiguity) is bliss. This equilibrium, in which nation-state actors may have similar doubts about their stockpiles has been described by the Calculated Equilibrium Doctrine that asserts that "the ambiguity involved in the issue of nuclear weapons contributes to national security."[66] Finally, to date, most world leaders have been reluctant to disrupt the current status quo for fear of re-legitimizing nuclear testing and as a consequence, potentially helping to advance an adversary's nuclear weapons technology.[67]

Environmental Issues. A lot of knowledge gained through nuclear testing unfortunately came at a price. The most significant underground testing accident was the containment failure in the 1970 BANEBERRY test in Nevada, during which a large radioactive cloud dispersed into the atmosphere. Some fallout, carried by the jet stream, travelled as far away as Vermont, over 2000 miles away.[68] This containment failure drove the nuclear enterprise to improve its understanding and characterization of geologic settings for underground testing.[69] Fortunately, nuclear accidents were a rarity after 1970.

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[65] Michael Bernardin, *Review of the Hopkins-Sharp Paper on Stockpile Stewardship Without Nuclear Testing*, (Los Alamos: Los Alamos National Laboratory, LA-UR-18-29194, September, 28th, 2018)

[66] Scott D. Sagan, "The Commitment Trap: Why the United States Should Not Use Nuclear Threats to Deter Biological and Chemical Weapons Attacks," *International Security*, Vol. 24, No. 4 (Spring 2000) p. 88-115

[67] U.S. Congress, House, Committee on Armed Services House of Representatives, Subcommittee on Strategic Forces, "Nuclear Deterrence—The Defense Science Board's Perspective." March 9th, 2017

[68] Glen McDuff, (Los Alamos Research Scientist, retired) interview by author. Los Alamos, NM, October, 1st, 2019.

[69] Wendee Brunish, *Containment of Underground Nuclear Tests: A Primer.* (Los Alamos National Laboratory, NM, April 23rd, 2014)

However, opening the door to a resumption of testing could increase the likelihood of an accident by less experienced nuclear powers.[70]

Breaking the Status Quo: Resuming Underground Nuclear Testing.

Aging Out and Building Ferrari's instead of Fords. In a 2009 report to Congress, former Secretary of Defense William Perry and former Secretary of Defense and Energy, James Schlesinger, stated the current approach to extending the life of the stockpile could not go on indefinitely:

> "The possibility of using this approach to extend the life of the current arsenal of weapons indefinitely is limited. It might have been possible to do so had the U.S. designed differently the weapons it produced in the 1960s, 1970s, and 1980s. But it chose to optimize the design of the weapons for various purposes, for example, to maximize the yield for the weapon relative to its size and weight. It did not design them for remanufacture. This approach also requires that the U.S. utilize or replicate some materials or technologies that are no longer available. Designs constraints also prevent the utilization of advanced safety and security technologies."[71]

Weapons currently in the stockpile, some fielded in the 1960s, were originally designed to last ten to fifteen years. To combat the effects of aging, a series of alterations and modifications have been conducted through the Life Extension Program (LEP) and alterations (referred to as Alts) to replace and refresh nuclear and non-nuclear components of the weapon. With each modification and update, the link between a current warhead and its originally tested design has grown more tenuous.[72] This concern is a reflection of the optimized way in which U.S. weapons were designed during the Cold War. U.S. weapons' designers used exotic materials and innovative designs to maximize a weapon's yield to weight ratio – (analogous to high-end, limited production cars like Ferraris). What this boils down to is that the

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[70] Of note, the 2019 Russian nuclear accident involving an attempt to recover a nuclear-powered missile from the bottom of the Barents Sea following a failed test is a reminder of the dangers involved in even tangentially related events that include nuclear materials. See an Arms Control Association report https://www.armscontrol.org/act/2019-10/news/us-intel-sheds-light-russian-explosion

[71] William J. Schlesinger, *America's Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States* (Washington D.C.: United States Institute for Peace Press, 2009) pp. 40-41

[72] Paraphrased from Medalia, RRW p.2

margins, "the amount by which the design parameter exceeds the performance minimum" is relatively small for U.S. nuclear weapons.[73] [74] As a result, their life expectancy may be less; returning to the car analogy, one can likely keep a Ford on the road much more easily than a Ferrari.

No Substitute for the Real Thing: Despite the great scientific advances made through SSP, many testing experts nonetheless believe that a return to nuclear testing may be required now, or in the near future, in order to certify weapon performance. They believe the current certification methodology employed by the SSP, which is based upon searching for, identifying, and correcting any discovered weapons deficiencies, may one day no longer be a suitable method given the advanced age of the stockpile. In other words, the task of finding critical "unknown unknowns" (or black swans) becomes more difficult with each passing day, despite SSP's best efforts to find them. According to these experts, testing is the gold standard for proving nuclear performance, and that the nuclear enterprise may one day need to again implement ongoing testing in order to mitigate risk and prove the veracity of these advanced aged weapons. [75]

Make Them Safer. Some experts argue that a return to testing isn't motivated by a desire to increase the military lethality of the weapons but rather to improve the safety and security or use control of current and future weapons. As stated by Siegfried Hecker, then-director of the Los Alamos National Laboratory, in a 1997 letter to Senator John Kyl, "…with a CTBT, it will not be possible to make some of the potential safety improvements for greater intrinsic warhead safety that we considered during the 1990 timeframe"[76] (author note: in other words, *before* a nuclear testing moratorium).

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[73] John C. Hopkins, (Former Los Alamos Laboratory Associate Director, responsible for Nuclear Weapons Program) and David Sharp (Los Alamos Fellow and former Chief Scientist) interview by author. Los Alamos, NM, October, 8th, 2019.

[74] Fred Mortensen. (Los Alamos Fellow and Design Leader) interview by author. Los Alamos, NM, April, 25th, 2020.

[75] For a more complete discussion on the need to return to some level of nuclear testing see John Hopkins, and David Sharp, "The Scientific Foundation for Assessing the Nuclear Performance of Weapons in the U.S. Stockpile is Eroding," *Issues in Science Technology*, (Winter 2019)

[76] Medalia, *Nuclear Warheads: The Reliable Replacement Warhead Program and the Life Extension Program,* 2007 pp. 19

Getting to Go: Some Recommendations to Improve Test Readiness Posture

To Test or Not to Test: Conditions that Could Drive us Toward Testing.

As stated earlier, questions of whether or not to resume underground nuclear testing are largely political and driven by geo-strategic conditions. After almost thirty years since the end of the Cold War, and the consequent hiatus from conducting nuclear tests, the U.S. has become desensitized to any situation that could warrant a return to Cold War style nuclear competition. Moreover, the global war on terror consumed much of the United States' strategic thinking such that concepts like nuclear deterrence and assurance fell by the wayside for many years. So, it's hard for Americans—from the senior leadership to the general public, to imagine an environment where the nation might be compelled to conduct a nuclear test.[77]

Lessons of History. Although the geo-strategic environment is much different, than it was during the Cold War, the Cold War provides some examples of periods when the U.S. had to play "catch-up" in the world of nuclear science to maintain and/or ensure *parity* and consequent *strategic stability* with the Soviet Union. The Soviets first discovered that a high-altitude electromagnetic pulse (EMP) could have a catastrophic effect on electronics and were the first to develop special alloys in their weapons to counter those effects.[78] The U.S., previously unaware, was forced to quickly follow suit. Additionally, Soviet scientists were the first to discover that the intense x-rays emitted from a nuclear explosion could be used to destroy a warhead's heat shield. Again, the U.S. had to move expeditiously to return to the drawing board to protect its weapons from a phenomenon an adversary had discovered.[79],[80]

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[77] Nina Tannenwald, "How Strong is the Nuclear Taboo Today?" *Washington Quarterly*, Issue 41, no. 3, (2019) pp. 89-109,https://doi.org/10.1080/0163660X.2018.1520553. Tannenwald's idea of the "nuclear taboo" is related.

[78] Houston T. Hawkins, "Rethinking the Unthinkable," *National Security Science Magazine*, (December 2014) p.14

[79] Hawkins, H., p.14

[80] (Joint Defense Science Board/Threat Reduction Advisory Committee Task Force 2010). In this 2010 study, the authors point out the need for renewed attention to nuclear weapons effects (e.g., EMP) vis-à-vis our nuclear enterprise. As pointed out in this paper, weapons effects testing was a major portion of our underground nuclear testing program. The Task Force report suggests nuclear survivability (e.g., defensive measures to ensure continued operations in radiation environments) has declined.

And perhaps the most compelling example of a historical lesson learned is the Soviets' sudden withdrawal from the testing moratorium in 1961. The Soviets went on to accomplish fifty-seven tests in the remaining three months of the year, to include the history's largest detonation--the fifty-five megaton Tsar Bomba. The great difficulty the United States faced in the aftermath to generate a timely and equivalent response formed the basis for today's test readiness safeguards.[81]

Black Swans, Grey Rhinoceroses, and Pink Flamingos. Surprise comes in many varieties and, as the Cold War examples above illustrate, can catch a nation and its leaders off guard and unprepared. Black swans, grey rhinos and pink flamingos are terms to characterize what former Defense Secretary Donald Rumsfeld called unknown unknowns (black swans); known unknowns (grey rhinos); and known knowns (pink flamingos). Furthermore, the adversary "gets a vote" and as Nassim Nicholas Taleb who coined the term in his book by the same title, a black swan *is perspective dependent*. In other words, a black swan event may be "a surprise for a turkey but not a surprise for the butcher" – so the object should be to "avoid being the turkey."[82] The nuclear weapons certification process is highly complex and, although the national laboratories have not encountered a significant issue to call the viability of the stockpile into question, the U.S. is still learning about the science behind plutonium aging and its associated impact on weapons components. In short, when it comes to the safety, security, and effectiveness of the nation's nuclear deterrent, the United States must have a plan to not suffer the same fate as the turkey.

Recommendations for Improving Test Readiness Posture

Take Inventory. First, the U.S. needs to assess exactly where it stands with respect to its test readiness posture – i.e., capabilities and deficiencies—and develop a plan for success. As discussed earlier, much of the material infrastructure, human capital, and specific organizational experience needed to resume testing has deteriorated or disappeared. While a lot of the hardware (cables, cranes, diagnostic

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[81] Notable Los Alamos engineer and scientist, Robert Osborne, stated "within 6 months of the moratorium the staff had dispersed to such a point that we had ***completely*** lost our ability to perform a comprehensive test." Glen McDuff "Primer: "Underground Nuclear Testing" LAUR-18-24015.

[82] Nassim Nicholas Taleb, *The Black Swan* (New York: Random House, 2007) pp. 93-94

equipment) no longer exists or needs refurbishment, more troubling is that the limited number of experienced scientists available to help develop, advise, and support the execution of a nuclear tests is diminishing with each passing year. Additionally, reviewing the regulatory environment's must-do's in advance, could rapidly improve the timeline to return to testing. Finally, scientists and policymakers must work together to identify the "least bad" of all available testing site locations to avoid paralysis should a test become required. Taking this inventory of extant capabilities sooner rather than later, and developing a plan, will help mitigate the natural degradation of material, people, and experience over time.

Capture Corporate Knowledge. Perhaps the most time-critical aspect of developing an effective test readiness plan is to take measures to ensure that the hard-earned corporate knowledge on how to accomplish testing is effectively captured and catalogued. Some efforts, like Los Alamos' National Security Research Center's endeavor to digitize and catalogue the over 10 million historical documents in its archive, are a step in the right direction. Efforts like this should be copied and accelerated across the enterprise. Additionally, steps should be taken to interview the last generation of nuclear testing scientists to capture their technical expertise and lessons learned. Fortunately, many of these scientists, like the ones that took the time to inform this paper, are still passionate about their experience and national security. They are eager and honored to pass on lessons learned to the next generations. Adequately capturing today's corporate knowledge, especially leveraging the human knowledge capital that still exists among the older scientists and engineers with nuclear testing experience is critical.

Leverage the Stockpile Responsiveness Program (SRP). As outlined in the 2018 Nuclear Posture Review, the SRP is a congressionally mandated program "that explicitly directs that the U.S. ensure the responsiveness and flexibility of our nuclear weapons infrastructure."[83] The SRP goal is to improve resiliency and responsiveness "via the full life-cycle spectrum of nuclear weapons conceptualization development, design, manufacture, and retirement to face technological surprise and

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[83] Office of the Secretary of Defense, *Nuclear Posture Review, 2018* (Washington D.C.: Department of Defense, 2018) p.63

potential geopolitical shifts in the future."[84] One of the main ways the SRP accomplishes these objectives is to expose early-career staff to challenging problems under the guidance of experienced mentors. While the scope of SRP is vast, if the program is properly funded, and includes a sufficient focus on test readiness, the SRP will, according to Michael Bernardin, at that time, the Los Alamos Associate Lab Director for Weapons Physics, "provide the opportunity to grow the needed expertise" to mitigate risk to national security."[85]

Rethink and Refresh the Arms Control Environment. Somewhat counterintuitively, a new look at arms control treaties may provide an opportunity to improve test readiness posture, avoid a "testing arms race," and enhance deterrence/assurance confidence. If major powers like Russia and China share similar concerns about weapons reliability, rather than "cheating" on existing treaties, they might find it advantageous to collaborate on an agreed-upon testing protocol.[86] For example, a relook and fresh interpretation and specification of language in the CTBT could provide the opportunity to engage **both** Russia and China on arms control around an issue of mutual concern.[87] Perhaps countries might agree to a construct which would allow for a limited number of tests, under scripted scenarios, during a defined time horizon, and within a very specific definition of allowable yield – e.g., an extremely small, underground hydronuclear test. This could allow participants a transparent and predictable option to gauge and reassess stockpile confidence **and** improve safety (nuclear surety). Additionally, this approach could reduce the risk of a "rogue defector" possibly triggering an all-out nuclear testing resumption. Re-engaging collaboratively in an arms control environment with the major nuclear powers may further concrete steps to reduce stockpiles while retaining the proven concept of "strategic stability" as a bedrock to prevent a nuclear exchange of any kind.

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[84] National Nuclear Security Administration, *Stockpile Stewardship and Management Plan, Fiscal Year 2020, Report to Congress* (Washington D.C. Department of Energy, 2019) p. 4-4

[85] Michael Bernardin, Los Alamos Associate Lab Director for Weapons Physics, *Review of the Hopkins-Sharp Paper on Stockpile Stewardship Without Nuclear Testing*, (Los Alamos: Los Alamos National Laboratory, LA-UR-18-29194, September, 28th, 2018) p.7

[86] DIA reported that there were concerns that Russia was cheating with regards to CTBT by conducting hydronuclear tests. See DIA Statement on Lt. Gen. Ashley's Remarks at Hudson Institute. https://www.dia.mil/News/Speeches-and-Testimonies/Article-View/Article/1875351/dia-statement-on-lt-gen-ashleys-remarks-at-hudson-institute/

[87] Note the U.S. (and others) CTBT status and "interpretation" of nuclear explosion in Art. 1 of the treaty.

Not a Stick but a Carrot: Hydronuclear Testing. The capability to conduct an extremely small yield (e.g., < 100 tons) nuclear test – a hydronuclear test – may offer the U.S. a number of advantages in several areas. These advantages could include a "carrot" in any new comprehensive, multi-party arms control arrangement that not only improves the safety, security, and effectiveness of the stockpile, but also negates any "asymmetric advantages" that may currently exist if, in fact, Russia and China have been cheating on existing treaties or "understood" nuclear testing norms.

The previous paragraph on the arms control environment alluded to the possibility that other nuclear states, namely, Russia and China, might be induced into a new or revised arms control agreement through the carrot of allowable "hydronuclear" tests. Advantages accrued to the parties in any potential agreement could "(re)level the playing field" in terms of stockpile confidence and security as well as provide a transparent mechanism for everyone to avoid the geopolitical downsides of abrogating existing agreements and/or getting "caught" doing so.[88]

Perhaps more importantly, the ability to conduct extremely small-yield hydronuclear tests would enhance capabilities to improve the safety, security, and effectiveness of the stockpile. As explained by a retired Los Alamos testing expert, "a little bit more yield, can be a lot more useful" and may provide some reassuring insights into weapons performance.[89] Furthermore, undertaking hydronuclear tests could be a key to opening some, but not all, of the "black boxes" that challenge the best science of the SSP – i.e., eliminate or mitigate the "black swans and/or grey rhinos" that might otherwise remain "unknown" until a crisis occurs.

There is some historical precedent regarding the benefits of hydronuclear testing when it comes to safety. In fact, scientists conducted a series of hydronuclear safety tests in the late 1950s to clarify some of the puzzling results regarding one-point safety of certain stockpile weapons already deployed to the

[88] A State Department report asserts Russia has conducted nuclear tests and has concerns about China adhering to a "zero yield" standard. Department of State. "Executive Summary of Findings on Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments." April, 2020 p. 7-8.

[89] Brunish, interview by author, 2019

field.[90] These tests occurred during a critical time in the Cold War--a test moratorium initiated by the Eisenhower Administration in late 1958. Calculations and hydrodynamic experiments were unable to resolve these problems that turned out to be reflective of a critical safety design flaw for four weapon systems that had become operational in 1958.[91] The military halted production and weapon handling procedures were severely constrained.[92] Los Alamos responded quickly with a proposal for a series of extremely small yield tests (i.e., hydronuclear) that could be conducted to help inform a solution to the safety problem. The Administration approved, the series was conducted (within the constraints imposed by the testing moratorium), and within four months, the most urgent safety questions had been answered. Without these tests, the likelihood that the nation would field weapons that weren't one-point safe was much higher. In fact, had the nation mistakenly fielded non-tested one-point safe weapons on the B-52 that crashed in Palomares, Spain, scientists estimated the chance of an accidental nuclear yield to be 1000 times greater.[93]

Finally, if the Russians and the Chinese have been conducting their own hydronuclear experiments (that would violate the U.S. understanding of language in the CTBT), a return to some kind of regime within which the U.S. *could* conduct these tests would go a long way to eliminating any technical advantages (i.e., strategic superiority) that our adversaries may have accrued by "cheating."

Coordinate and Collaborate. During the period of time when the U.S. conducted nuclear tests, the national labs, Los Alamos, Lawrence Livermore and Sandia, were permitted wide discretion to determine how to conduct their respective nuclear tests. This meant that each lab often took a different approach and adopted different specifications for racks, canisters, test hole dimensions, and other methodological differences. The labs could revive and review recommendations from the now defunct Joint Testing Organization to ensure coordination and collaboration if necessary. This would prevent unnecessary slowdown in the event PDD-15, with its two to three-year timeline, is executed. Related to

[90] Robert N. Thorn and Donald R. Westervelt, *Hydronuclear Experiments*, (Los Alamos: Los Alamos National Laboratory, February, 1987), "One-point" safety implies a nuclear detonation may not start "at any single point on or in the explosive components." In other words, if a bullet hits the weapon it should not explode. p.3

[91] Thorn and Westervelt, p.2

[92] Thorn and Westervelt, p.4

[93] Thorn and Westervelt, p.5

lab-to-lab coordination (that should be easier today due to the establishment of the National Nuclear Security Administration), an assessment of the regulatory environment would help planning and improve timeliness. Given the more stringent and necessary safety and environmental concerns since 1992, a menu of options, key regulatory "must-dos", and challenging issues could be identified and resolved ahead of time, avoiding paralysis should an Administration order testing resumption.

Conclusion

The United States has continued to abstain from nuclear testing since 1992. Regardless of one's position on the merits or lack thereof when assessing a resumption of nuclear testing, the act of actually performing nuclear tests should not be confused or conflated with the nation maintaining a capability to do so as stipulated by Presidential Decision Directive.

As nearly three decades have passed since the country's most recent nuclear test, it is easy to forget the origins and context that drove PDD-15 and the safeguards. Both were crafted and agreed upon by the Executive and Legislative branches of government as well as the DOD, to ensure conditions to resume nuclear testing were maintained even under the most favorable of geo-strategic conditions. Hard lessons from the Cold War were learned and the safeguards were modified over time to reflect those lessons. As time has passed, these guideposts have faded from the collective consciousness yet, these hard-earned lessons of past presidents, statesmen and military leadership remain important reminders with respect to national security.

So too, in some sense, have the aspirations of global collaboration faded as nation-states return to mimic, in many ways, the great power competition that existed in the late 1800s and post World War I. A nuclear-armed Russia is challenging the European order and China is attempting a revision to the rules-based international norms that have existed since the end of World War II. Both of these competitors have modernized their nuclear forces in earnest while the U.S. capability aged and, in some respects, atrophied. Their aggressive modernization programs--conventional, nuclear, and non-conventional, that are underway across multiple domains, threaten to upset the strategic stability that has existed since the end of the Cold War. These threats became clearer as events unfolded in the Ukraine, through destabilizing actions regarding U.S. domestic politics, in the South China Sea, and with the creation of organizations that upset and offset long standing international norms in the economic and technology sectors, to name just a few examples.

As a result, the U.S., specifically the DOD and DOE, have engaged in a massive effort to reconstitute the nuclear enterprise. Through the creation of Air Force Global Strike Command, a reinvigoration of the ICBM force, and a national security strategy that gives nuclear forces a seat at or near the head of the table, the nation's nuclear deterrent is on the road to recovery. Funds are being allocated to modernize the three legs of the triad and a renaissance of strategic deterrence thinking is underway across government institutions, private sector think tanks, and in academia. The partnership between DOD and DOE that can trace its roots to the Manhattan Project is being revitalized as both organizations collaborate even more deliberately on key nuclear national security programs like SSP, SRP, LEP's, Alts, gaming, modeling, and personnel exchanges like the Air Force Fellows program though which this paper was written.

Many challenges remain as the U.S. works to rebuild and improve the health of its nuclear enterprise and infrastructure. Competing priorities exist, as DOE and DOD attempt to modernize all legs of the triad **and simultaneously** rebuild and improve the material and personnel resources of the critical national laboratories. Test readiness posture may not make the cut in terms of the lengthy list of wicked problems facing the enterprise. However, as is pointed out in this paper, the longer the nation waits, the more intractable this problem becomes.

It is much preferred to address the shortcomings surrounding nuclear test readiness posture now and develop a plan so that if a national security situation arises and the nation needs to conduct a test, it can. History has taught us, particularly in a world defined by Great Power competition, that the next emergency is likely just around the corner. The impact of black swans, grey rhinos, and pink flamingos becomes higher and more consequential the less prepared the nation is for a surprise. The longer the nation's current posture atrophies the more the problem will have to be reframed as *reinventing* testing rather than *resuming* it.

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Appendix A: A Representative Sample of U.S. Nuclear Tests

	Testing Spectrum	Test/Event	Date	Type/Location	Notes
1	**Subcritical**	REBOUND	2 Jul 1997	Underground @ U1a, NNSS	This was the first subcritical experiment conducted after the testing moratorium announced in 1992.[1]
2	**Hydronuclear**	Multiple series of tests	12 Jan 1960[2]	Underground @ Los Alamos	The first of eight tests in a series that ended 11 February, these were a series of safety experiments that identified then extant one-point safety problems and drove remedial action to improve safety features in the stockpile.[3]
3	**Demonstration of Resolve**	First operational combat use	6 Aug 1945 9 Aug 1945	Airdrop @ Hiroshima, Japan Airdrop @ Nagasaki, Japan	While not considered tests, one could argue that the two atomic bombings to end the war with Japan fit the definition. Two nuclear weapons that the United States exploded over Japan ending World War II were not "tests" in the sense that they were conducted to prove that the weapon would work as designed (as was the first test near Alamogordo, New Mexico, on July 16, 1945), or to advance nuclear weapon design, or to determine weapons effects, or to verify weapon safety, as were the more than 1,000 tests that have taken place since June 30, 1946.[4]
4	**Stockpile Confidence**	Multiple series of tests	1979-1986*	Underground @ Various locations, NSSS	Seventeen tests (*included four tests from the early 70's not called Stockpile Confidence Tests [SCTs]) were conducted on each weapon type; there were no catastrophic failures.[5]
5	**Lower Yield or Effects**	HURON KING	24 Jun 1980	Underground @ U3ky, NSSS	This tested the radiation hardness of the then new DOD Defense Satellite Communications System. It was a combination Los Alamos-DOD test.[6]
6	**Larger Yield**	HANDLEY	26 Mar 1970	Underground @ U20m, NSSS	This was one of the largest detonations conducted at NSSS. The test was part of fifty-two tests in Operation MANDREL, 1969-1970.[7]
7	**Full Experimentation**	GRABEL	25 May 1953	Airburst @ Area 5, NSSS	This was a test of the Mk9 nuclear weapon from a 280mm cannon.[8]

Notes.

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